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Technical Note 94-1

DESIGN CONCEPTS FOR AN INTEGRATED ENVIRONMENTAL MEDICINE WORKSTATION FOR PREDICTION, SIMULATION, AND TRAINING

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

December 1993

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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DESIGN CONCEPTS FOR AN INTEGRATED ENVIRONMENTAL MEDICINE WORKSTATION FOR PREDICTION, SIMULATION, AND TRAINING

by

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13. ABSTRACT (Maximum 200 words)

A design concept is developed for a comprehensive multimedia software-based environmental medicine and physiology workstation for military health care planners and providers for use in both operational and training settings. This will be based on integrating a core of predictive models for soldier responses to hot, cold, and high altitude stress. Overlying this core is a layer of on-line documentation to provide assistance and guidance as well as ~~to~~ support training modes. The user interactive information resource will incorporate USARIEM's cumulative database in hot, cold, and altitude stress as well as nutrition, human performance, and injury prevention. The outer layer of the workstation is a flexible, user friendly, graphical interface. It may also be tailored as an environmental medicine computer-based training module for medical students and residents.

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EXECUTIVE SUMMARY

This technical note describes a design concept for a comprehensive multimedia software-based environmental medicine and physiology workstation for military health care planners and providers in both operational and training settings. This workstation relies on the integration of predictive models for hot (e.g., the extensively validated USARIEM heat stress/strain model), cold, and high altitude stress. Overlying the computational core of the workstation is a layer of on-line supporting documentation, primarily USARIEM environmental medicine field manuals, to provide assistance and guidance as well as provide for training modes.

In a training context, the workstation may be utilized, for example, at the Uniformed Services University of the Health Sciences School of Medicine to familiarize medical students, via simulations, with the variables that determine environmentally induced stress, physiologic strain, performance decrements, and clinical illnesses and injuries. Operationally, field surgeons will use it to determine work-rest cycles and optimum salt intake for hot climates, rations that maximize performance in cold weather, as well as preventive measures for deployment to high altitudes.

A prototype under development assists in defining the scope of the project, distinguishes what will be difficult or easy to accomplish, suggests what implementation resources are required, and provides a tool for identifying problems with the user interface. Multimedia extensions will require a comprehensive production plan for short and long-term horizons.

This product will facilitate determination of adverse physiological, performance, and medical effects of environmental stressors in military operational and training settings and suggest strategies to reduce environmental casualties.

INTRODUCTION

Medical officers (brigade, division and corp surgeons), as well as personnel on preventive medicine teams and field hospital staffs are often required to provide advice to commanders and their staff as well as other military personnel, on issues that relate to avoiding or minimizing adverse impacts of environmental stress. The software product described in this technical note assists field medical officers and health care planners with the systematic evaluation of the environmental threats to health and performance. Analysis of the environmental threat then provides a rational basis for plans and advice intended to mitigate the environmentally stressful conditions that troops are expected to encounter. Unacceptable health and performance decrements can therefore be avoided.

This technical note delineates a concept and identifies high level design considerations for development of a comprehensive software package that integrates knowledge and data models for heat, cold, and altitude into a unified environmental preventive medicine decision aid for military health care planners and staff officers. It exploits USARIEM's institutional expertise in such areas as cold, heat, altitude physiology and medicine, nutrition, and injury prevention to develop a comprehensive environmental medicine workstation prototype, followed by a validated operational version.

In its full manifestation, the product will include on-line context-sensitive retrieval of information from relevant unclassified USARIEM technical reports as well as selected references from the scientific literature. It not only will provide predictive capabilities but also training opportunities. Additionally, it will manifest a flexible, state-of-the-art interface and incorporate multimedia where this will enhance understanding or add training impact.

Utilizing USARIEM's Heat Strain Model, Science Applications International Corporation (SAIC) has developed an operational PC-based Heat Strain Decision

Aid (SAIC, 1993). Because it was intended for actual military planning, it was limited in scope by the lack of availability of validated, operationally focused, algorithms for predicting the physiologic effects of cold and high altitude environments. The principal objective of the present proposal is to explore the feasibility of greatly expanding the Decision Aid concept by including additional modules currently under prototype development for cold and altitude, on-line text and doctrine, and additional components to permit interactive training for topics in environmental medicine, physiology, and deployment medicine. The uniqueness of the project is that it will allow users to access much of USARIEM's knowledge base in these areas within a single, comprehensive, multipurpose resource. The design and development is, in essence, an integration process. Duplication of previous achievements in modeling and simulation of physiologic strain due to environmental stresses will be avoided.

Figure 1 below is a flowchart that depicts the principal components of the design concept. The following section provides explanations of the numbered flowchart elements with paragraph numbers corresponding to those in the flowchart.

DESCRIPTION OF THE PRINCIPAL DESIGN COMPONENTS

1.0 User:

As previously stated, the intended principal users are military health care planners. This includes, for example, preventive medicine officers serving as advisors to command staffs of line units. It would, however, also be applicable to other health care professionals interested in estimating estimating the environmental components of disease and nonbattle injury (DNBI). Casualty prediction tables in the U.S. Army field manual FM 101-10-1 currently do not allow direct prediction of DNBI due to environmental stress.

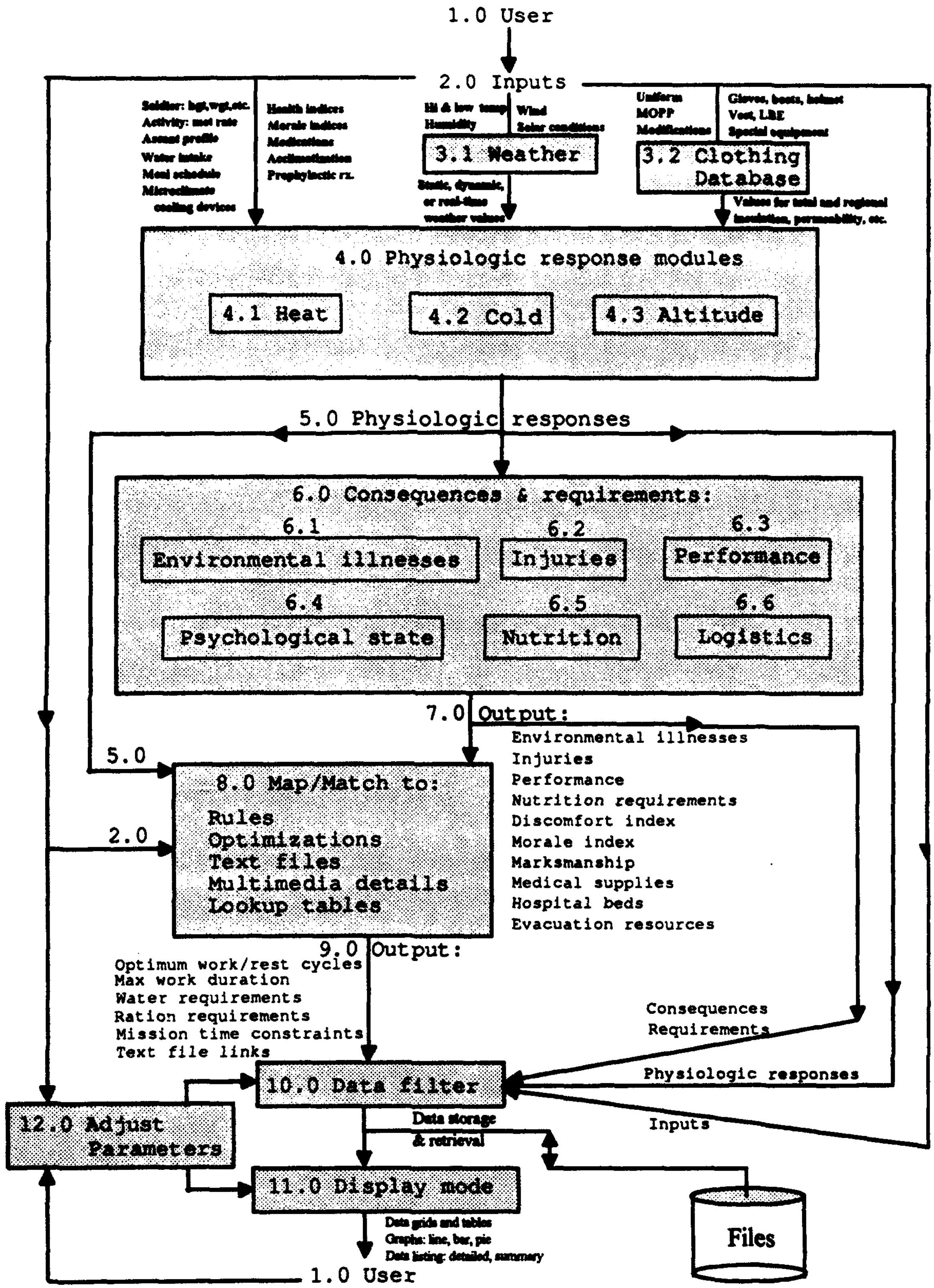

Figure 1. Top level design scheme

Research physiologists as well as physiology students at universities and colleges are additional types of users for which the product could be tailored. For the research physiologist, the product will allow simulation of the physiologic effects of environmentally stressful conditions as a preliminary step in evaluating study design options. This is particularly important with respect to complying with test subject safety issues and restrictions such as core temperature and heart-rate limits (USARIEM Type Protocol, 1992). The workstation will also provide physiologists or environmental medicine research scientists with a software tool facilitating the development of responses to requests from field units on specific environmental medicine advice. This product will be designed to facilitate the generation of customized tables for such items as work-rest cycles, maximum-work times, recovery times, and hourly water requirements.

As a training and professional development tool the workstation can be tailored for use by medical students; for example, those attending the USUHS Medical School as well as individuals in preventive, occupational, aerospace medicine, or other primary care residency programs. During medical school or residencies, there is often little or no training time specifically devoted to environmental medicine issues. This product can be tailored to provide a dynamic, self-paced method for medical students and residents to explore and simulate the physiologic and medical effects of environmental stressors. Medical students, residents, and some practicing physicians, for example, are frequently not well acquainted with variables that influence exertional core temperature profiles in hot weather. In part this is because core temperatures of heat injury patients often have fallen, sometimes to normal, by the time the patient has been brought to the emergency room or treatment facility. Moreover, the relationships or correlations between a wide variety of soldier, environmental, and mission factors on the rate of rise of core temperature may not be immediately obvious to those not immersed in this area. A simulation tool can clarify these factors for the student or physician in training. The relative importance of a wide range of inputs can be explored by using the simulator in a parameter sensitivity mode.

Figure 2 below depicts an example of an entry screen for the environmental medicine and physiology workstation.

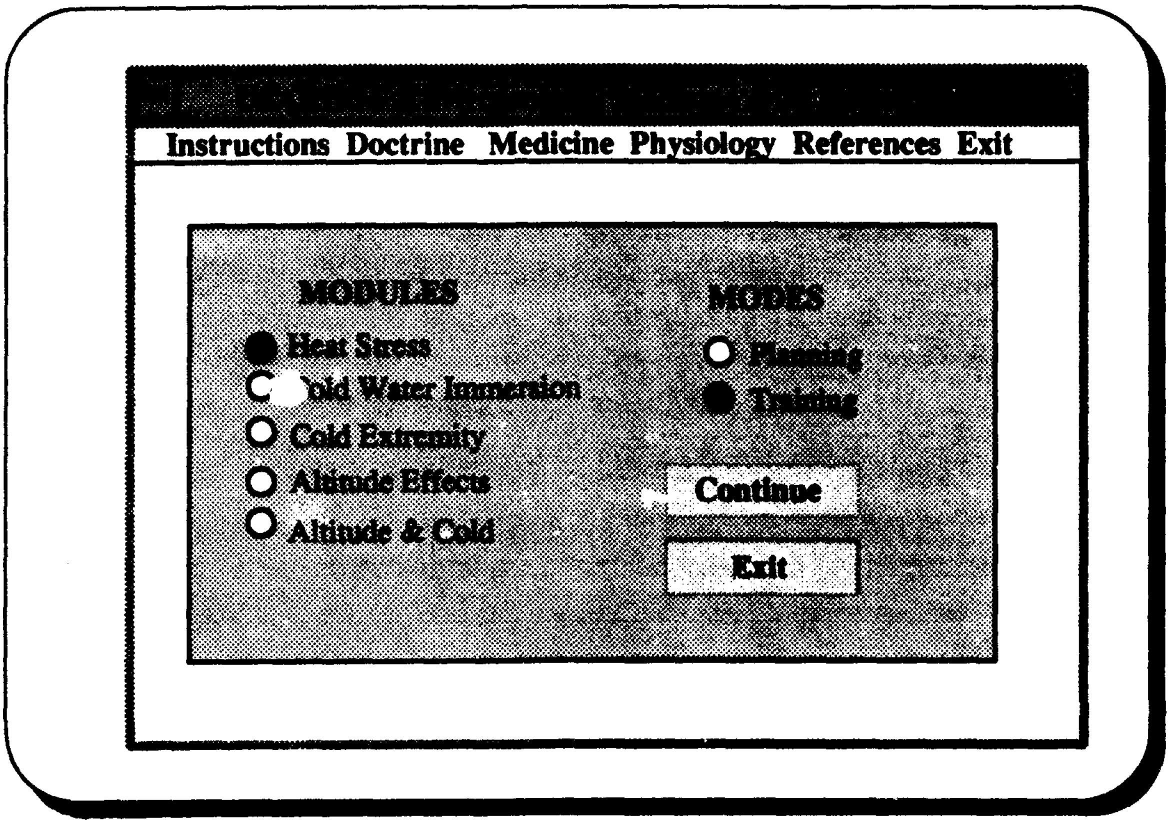

Figure 2. Example of initial entry screen.

This illustrates modules and options the user may select from. In this example, the user is directed to the heat-stress module in a training mode when the Continue button is clicked. Note that the initial screen has a bar menu that allows perusal of military medical doctrine such as technical notes or medical field manuals for military operations in heat, cold, and altitude (e.g.: Burr, 1993; Burr, 1991; Glen et al., 1990; Jones et al., 1993; Modrow et al., 1993; Thomas et al., 1993; Young et al., 1992). This is a location in the application where service specific adaptation can be accommodated. Additional bar menu items provide for more conventional medical and physiology reviews developed from the scientific literature and standard reference texts. A comprehensive list of

references will also be available. The references will indicate the literature drawn upon for the program itself as well as for the main topic areas. It may be feasible to include a module that permits the user to update or customize the reference lists by uploading from reference lists files created by on-line medical reference and abstract services.

2.0 User Selected Inputs to the Program: to avoid redundancies, potential inputs are listed below grouped according to physical or functional objects (objects will be discussed in a latter section) rather than according to requirements of the separate heat, cold, altitude or other modules that accept the inputs.

2.1 Soldier(s):

- Height, Weight, Percent body fat
- Age, gender → predicted maximum heart rate and maximum rate of oxygen uptake
- Days acclimatized to heat, cold, or altitude
- Medications, e.g., pyridostigmine, atropine, acetazolamide, decadron.
- Physical conditioning
- Initial values for body compartment temperatures: skin, core, muscle, fat, blood
- Initial values for heart rate, percent dehydration, blood volume distribution

2.2 Environmental Inputs:

- WBGT or dry bulb temperature, humidity, wind speed, solar radiation
- Maximum and minimum expected daily temperatures and standard deviations
- Solar load
- Month → sunrise and sunset times (modulates solar load)
- Country → average latitude (modulates solar load)

- Altitude
- Precipitation
- Water temperature if immersed

2.3 Activity Inputs:

- Sequence of activities
- Onset time and duration of each activity
- Amount of time allowed to complete the sequence of activities
- Metabolic rate associated with each activity either as direct input of metabolic rate or chosen from a menu or if marching
- Marching parameters for speed, load, grade, and terrain
- Work-rest cycle times (user defined, therefore not necessarily optimum)
- Water intake schedule
- Altitude ascent staging schedule

2.4 Clothing:

- Selecting clothing and MOPP status from a menu generates the appropriate values for clothing insulation (Clo), water vapor permeability, and associated wind velocity correction factors
- Modifications to the selected uniform, e.g., collar buttoned/unbuttoned, sleeves up/down, trousers tucked/untucked into boots
- Headgear
- Gloves
- Footwear

2.4 Threshold values for warnings or output data labeling:

- Maximum or minimum permissible core temperature, heart rate, dehydration level, percent casualties, arterial oxygen saturation, arterial pH
- Maximum or minimum rates of change of predicted physiologic responses
- Maximum rates of body heat storage or heat loss

Figure 3 below illustrates how inputs may be grouped using a grid format for a heat-stress module.

	Set# 1	Set#2	Set#3	Set# 4
Number of troops:	100	100	100	100
Avg hgt (inches):	70.0	70.0	70.0	70.0
Avg wgt (lbs):	160.0	160.0	160.0	160.0
Days acclimatized:	10.0	10.0	10.0	10.0
Initial core temp (F):	98.8	98.8	98.8	98.8
Avg. skin temp (F):	96.8	96.8	96.8	96.8
Initial dehydration (%):	1.24	1.24	1.24	1.24
Clothing:	BDU	BDU	BDU	BDU
Dry bulb temp (F):	95.0	100.0	105.0	110.0
Rel humidity (%):	20.	20.	20.	20.
Wind speed (mph):	2.0	2.0	2.0	2.0
Work solar(rest in shade):	Full sun	Full sun	Full sun	Full sun
Activity:	Marching	Marching	Marching	Marching
Metabolic rate (watts):	438.03	438.03	438.03	438.03
Required work time (mins):	240.0	240.0	240.0	240.0
Max allowed time (mins):	500.0	500.0	500.0	500.0
Work/Rest cycle (mins):	50.0 10.0	50.0 10.0	50.0 10.0	50.0 10.0
Drinking water (qts/hr):	1.0	1.0	1.0	1.0
Meals/day & mg Na/meal:	3 1822.0	3 1822.0	3 1822.0	3 1822.0

Figure 3. Example of input grid for a heat-stress module.

Note that some of the inputs relate to time, obviously a very important issue in military operations. Occasionally, sound preventive medicine recommendations for work-rest cycles will extend mission completion time. The commander should be notified of this operational cost versus the physiologic and performance benefits accruing to the recommended work-rest times. For short duration missions an alternative may be to go with the predicted maximum one-time work period.

3.0 Front-end Support Modules:

3.1 Weather effects options:

A. Static: user selects weather inputs, e.g., temperatures, wind speed, humidity, etc., for a specific situation. These values do not change as a function of simulated time. This is the mode that is utilized by the current

version of the SAIC Heat Stress Decision Aid and other USARIEM heat-stress models.

B. Dynamic: implemented as a virtual weather "machine". For this the user inputs maximum and minimum expected daily temperatures, wind speeds, humidity, and solar radiation along with corresponding standard deviations. These values are then utilized by an algorithm that generates time-varying simulated weather outputs for each time step. This will be based on development or acquisition of a suitable predictive meteorologic model that takes into account time of year and global location.

C. Real-time: inputs from weather data sources or stored meteorologic data files as well as other devices such as global position systems (GPS). USARIEM has recently completed experimental chamber testing of a digital heat stress monitor (HSM). This HSM captures real-time WBGT data as part of the input to a version of the USARIEM Heat Strain model programmed into a RAM chip within the device. An additional USARIEM project as described by Santee et al., 1992, involves incorporating the USARIEM Heat Strain software module into the Integrated Meteorological Tactical System (IMETS). This will allow the current model to utilize real or near real-time weather input from multiple sensors including satellite sources. Also, terrain related data such as slopes, type of terrain (terrain coefficients), and automatic determination of shaded locations will be available as time and space varying inputs. Future consideration should be given to developing data link protocols to allow the field medical staff officer direct access to the medically oriented outputs of the IMETS system from within the environmental medicine and physiology workstation. For example, a modem connection could permit uploading of digital images of the IMETS's predicted heat stress contours as well as subsets of the IMETS's meteorologic data.

3.2 Clothing Database:

- Tables of insulation (clo), water vapor permeability, and corresponding wind velocity correction coefficients
- Headgear parameters
- Footwear parameters
- Effects of additional equipment, e.g., ballistic vests, rucksacks, parachute packs, etc.
- Correction factors for clothing modifications such as sleeves up/down, collar buttoned/unbuttoned, trousers tucked/untucked into boots

The USARIEM military clothing database is extensive and continuously updated. Further work will be required to determine the effects of uniform modification on unmodified total insulation and permeability values. Although biophysical values for boots are available, the feet have not been explicitly included in any of the USARIEM heat-stress models. Work is currently in progress on developing a digit and extremity model for cold weather. In the future, it may be possible to extend the cold extremity model for use in predicting the contribution of the extremities in thermoregulation in hot environments. At that point this could be included as additional nodes in the six-node lumped parameter model described by Kraning,1991.

4.0 Physiologic Response Modules:

4.1 Heat Strain: this module generates predicted physiologic responses as functions of such intermediate outputs as body compartment temperatures, water and sodium losses from sweating, and heat-rate profile as functions of simulated time. This module can be implemented using either the empirically based USARIEM Heat Strain algorithm (Pandolf et al., 1986) or the lumped parameter six-compartment heat strain model as described by Kraning, 1991.

4.2 Cold Strain: this module also generates predicted body compartment temperatures and also an index or metabolic contribution of shivering and cold induced vasodilation. USARIEM algorithms are available for predicting physiologic responses to cold water whole body immersion as described by Tikuisis et al., 1987, as well as an evolving extremity model described by Schitzer et al., 1990. The cold water immersion algorithm can be utilized for prediction of central hypothermia whereas the cold digit or extremity model may predict the potential for peripheral cold injuries such as frostbite and trenchfoot.

4.3 High Altitude Strain: this module will predict the expected physiologic effects of hypobaric, hypoxic environments primarily in terms of time- dependent respiratory, hemoglobin oxygen saturation, cardiovascular, and acid base responses. Because ambient temperature decreases as a function of altitude, this module may be directly linked or integrated with the cold strain module. Currently effort is being made to expand a static hypoxia model based on work by Kessler, 1980, into a dynamic physiological strain algorithm capable of predicting operationally useful outputs for high altitude missions.

5.0 Outputs #1: Physiologic Responses: the outputs from the physiologic strain modules described above can serve as inputs to the medical and performance effects module. Also, they can be viewed by the user as primary output presentable in various formats - tabular, graphics, or detailed data listings. Likewise they can be filtered by pattern recognition routines and subsequently linked to rules and text files that will provide the user with appropriate explanations, advice, or warnings. Specific outputs would include:

- Core temperature
- Other body compartment temperatures
- Transcompartmental heat flows
- Compartmental heat storage

- Finger or toe tip temperature
- Skin temperature
- Heart rate
- Compartment blood flow distributions
- Sweating rates and cumulative fluid losses
- Alveolar, arterial, and venous oxygen pressures
- Hemoglobin saturation
- Compartmental oxygen utilization rates
- Blood pH and bicarbonate levels

Figure 4 below illustrates an example of an output grid for a heat stress module. Most of the data are physiologic in nature, a few are medical which is discussed in the next section.

	SET# 1	SET# 2	SET#3	SET# 4
Number of troops:	100	100	100	100
% heat casualties:	14.58	41.68	85.98	99.39
# of heat casualties:	15.	42.	86.	99.
Max. core temp:	102.6	103.	103.6	104.2
Hours to max core temp:	3.833	3.833	3.867	3.867
Max. sweat rate (lts/hr):	1.134	1.155	1.18	1.21
H2O consummed/man (lts):	4.833	4.833	4.833	4.833
Sweat loss/man (lts):	4.623	4.814	5.107	5.337
Net H2O/man (lts):	-0.6027	-0.7936	-1.087	-1.317
% dehydration:	0.8304	1.093	1.497	1.815
Min lts needed for unit:	408.3	427.4	456.7	479.7
Max heart rate (bpm):	184.2	191.8	199.	205.5
Hours to max heart rate:	4.033	4.033	4.033	4.033
Hours needed for mission:	4.833	4.833	4.833	4.833
Allowed-required hours:	3.5	3.5	3.5	3.5
Max nonstop work (min):	91.61	77.29	66.56	58.06
Cool pow in shade (watts):	3.786	3.181	2.546	1.88
Dietary Na (gms):	5.466	5.466	5.466	5.466
Sweat Na loss (gms):	5.813	6.04	6.388	6.663
Net (diet-sweat) Na (gms):	-0.3469	-0.5739	-0.922	-1.197

Figure 4. Example of a physiologic response output grid for a heat-stress module.

6.0 Medical and Operational Effects Module: this module predicts the consequences of excessive environmental strain in terms of heat, cold, and

altitude related illnesses, injuries, and performance decrements. The operational significance of the logistic support required to care for these environmental casualties can also be predicted. Logistic support output will include numbers of medical personnel, evacuation assets, and medical supplies required to treat and transport these DNBI casualties. Operational significance will be also be expressed in terms of unit performance degradation, unit morale decrements, and attrition. Other predictable operational requirements will include such items as potable water, salt replacement, and nutritional support.

6.1 Environmental illnesses: this submodule produces predictions of expected incidence of various categories of heat illnesses, cold injuries (Sampson et al., 1983), and altitude related syndromes as a function of some or all of the inputs and physiologic strain response module outputs. Likewise, these illness and injury predictions can be cross-checked with user defined thresholds to determine limits on exposure times or other parameters. This will ensure that the occurrence of environmentally induced illnesses and injuries, decrements in performance, or index of unit effectiveness remain below the desired, or acceptable, limits.

The USARIEM Heat Stress/Strain Model currently predicts the expected gross incidence or total number of all types of heat exhaustion and heat stroke as a function of predicted core temperature. This can be expanded to provide the predicted distribution with respect to generally recognized categories such as mild, moderate, and severe heat exhaustion and heat stroke. It may become feasible to predict the expected number of sunburn injuries in hot dry conditions or miliaria (heat rash) in hot humid conditions as a function of solar load, temperature, humidity, clothing characteristics, exposure time, and body surface area covered by clothing.

6.2 Injuries: this submodule associates activity related parameters to various types of predictable skeletal-muscular injuries. This will include predicting

foot blisters and stress fractures associated with prolonged marching, muscle strains and lower back problems associated with carrying or lifting heavy loads, and contusions or bruises associated with combat type of maneuvers or training (Knapik et al., 1992)

USARIEM's Occupational Medicine Division has databases related to training and road march injuries. Also, data from numerous footwear studies are available for future modeling efforts pertaining to the predictive factors and possible mechanisms in foot blister formation. Skeletal-muscular injuries are particularly common and important in Army Infantry, Ranger, and Special Operations units. It will be useful to predict, for example, the incidence and amount of unit performance degradation due to foot blisters and other injuries for a tactical road march using work-rest times recommended by the heat-strain module.

6.3 Performance: this submodule provides a correlational connection between the outputs from the physiological response module and decrements in soldier performance. It has been well established by numerous investigators that even if individuals do not become obviously sick or injured, performance on a variety of motor and cognitive tasks may well be adversely affected by environmentally induced stress (Banderet and Burse, 1991; Kobrick and Johnson, 1992; Sampson et al., 1983; Taylor and Orlansky, 1993). In other words, performance degradation is an indicator of environmentally induced strain perhaps less overt than illness and injury but not necessarily less significant from an operational point of view.

Some specific measures of performance might include effects on:

- Marksmanship:
  - siting time
  - distance of shot group center of mass from center of target

shot group dispersion

- Vigilance:
  - sensory detection threshold changes
  - target recognition an discrimination

- Decision making and cognitive skills, e.g., error rates for solving:
  - operational problems
  - word problems
  - numeric problems

6.4 Psychological state: this submodule is primarily directed toward providing predictive capability with respect to how environmental stress impacts on the psychological well-being of the individual and the unit. From a military perspective this is best summarized by the well known term, "morale". It may well suffice to generate only a global morale decrement index anchored to some presumably normal or environmentally unstressful condition. It may, however, be possible to generate more specific predictions of psychological effects. There are numerous USARIEM technical reports available that demonstrate the many adverse psychological effects of environmental stress based on observations and use of questionnaires during environmental stress studies. Many of these studies have used the Environmental Symptoms Questionnaire (ESQ) (Sampson and Kobrick, 1980).

6.5 Nutrition: this submodule will determine the metabolic and nutritional requirements imposed by the input scenario(s). For example, the metabolic rate and duration of specified activities are translated to caloric requirements. Specific activity profiles can be automatically recognized as indicating special types of rations. An example for such a case is identifying the appropriateness of long range patrol (LRP) rations for scenarios specifying small numbers of troops going on long range patrols. This submodule will enable military

physicians unfamiliar with different rations and their intended uses, to provide nutritional advice intended to optimize soldier health and performance. It can also suggest the logistic advantages of specially configured ration types. To generate this output, an on-line nutritional database will be available. This will allow calculation of such things as ration weight, water and salt content, as well as other nutrient information. It will permit the military health care advisor, planner, or provider to readily answer technical questions soldiers and staffs may have about nutritional requirements for optimal performance in harsh environments.

6.6 Logistics: medical consequences will be linked with their logistical implications. These include requirements for medical supplies such as intravenous fluids, evacuation assets, hospital beds, oxygen supplies, and medicinals such as acetazolamide. In some circumstances, environmental medical problems may impose significant additional logistic requirements. Such may be the case for unacclimatized units tasked to suddenly deploy to high altitude or hot weather environments. Very cold weather may also increase medical logistic needs. The ability to properly forecast these additional requirements may facilitate planning and implementing medical support and perhaps avoid preventable initial entry supply and resource deficiencies.

7.0 Output #2, Outputs form the Medical and Operational Effects Module:

7.1 Environmental Illnesses:

7.1.1 Heat; expected # and % with:

- heat stroke
- heat exhaustion
- heat cramps
- dehydration

- sunburn
- miliaria

7.1.2 Cold; expected # and % with:

- frostbite
- trenchfoot
- hypothermia
- shivering

7.1.3 Altitude; expected # and % with:

- acute mountain sickness (AMS)
- high altitude pulmonary edema (HAPE)
- high altitude cerebral edema (HACE)
- decompression sickness
- dehydration
- thrombotic complications
- complications due to medicinal prophylaxis (e.g., acetazolamide)

7.2 Injuries: expected # and % with:

7.2.1 Skin:

- blisters
- dermatitis, e.g., miliaria

7.2.1 Musculo-Skeletal:

- strains
- sprains
- tendonitis
- plantar fascitis
- stress fractures
- other injuries e.g., "rucksack" palsy

7.3 Performance: expected decrements in:

7.3.1 Marksmanship:

- siting time
- shot group center of mass from target center
- shot group tightness

7.3.2 Vigilance:

- detection thresholds
- target recognition

7.3.3 Decision and problem solving error rates:

- operational scenarios
- word problems
- numeric problems

7.4 Nutritional consequences:

- weight changes
- caloric requirements
- salt requirements
- dietary respiratory ratio
- lean body mass and fat changes
- nutritional deficiencies

7.5 Psychological and morale indices:

- discomfort
- fatigue
- hunger
- thirst
- stress
- strain

7.6 Logistic requirements:

- potable water per soldier and per unit
- IV fluids and associated supplies
- medications, e.g., acetazolamide
- oxygen
- blister treatment supplies
- splints and bandages
- number of beds in treatment facilities
- evacuation assets

8.0 Post processor: this module can suggest optimum values for soldier or mission parameters that will minimize adverse environmental consequences. When the workstation is used in its training and instructional modes this module can generate the "correct solutions" to compare with the user generated data. This module may utilize submodules that exploit:

8.1 Rules (or so called AI): these are often dynamic databases of constructs such as

IF (#, %, rate, value, state, etc.)
THEN (notify user that a particular type of situation has been detected, generate an action, or ask user a question).

8.2 Optimization routines for optimum:

- work-rest cycles
- maximum work and recovery times
- water consumption schedules
- high altitude acclimatization
- hot weather acclimatization
- clothing configuration
- nutritional support

8.3 Text files as on-line or context sensitive references :

- military doctrine for control of environmental stressors
- prevention and treatment
- nutrition
- physiology
- list of references
- system help
- outline of program modules

8.4 Multimedia support for on-line assistance, triggered by a pattern recognition routine, or for feedback and instructional purposes:

- interactive video to maximize impact where dynamic visual effects can be expected to enhance attention, understanding, or learning retention
- terrain databases and photos to acquaint the user with the geographical area of interest as well as providing the base for sensor or satellite derived meteorological data
- sound to alert user to specific conditions or to enhance feedback, attention, and retention. Sound should generally be a user selectable option.

8.5 Look-up tables or standard database structures are another method of enhancing the breadth and expandability of the product.

9.0 Post- processor outputs:

9.1 Heat stress:

A. optimum values:

- work-rest cycles
- maximum work and recovery times

- hourly water consumption

B. pattern detection:

- sources of excess heat stress in current scenario(s)

C. links to:

- heat stress physiology, medicine, and operational on line references
- multimedia heat illness case presentations

<u>9.2 Cold stress:</u>

A. optimum values:

- minimum time to reach threshold fingertip or toe temperatures
- maximum exposure times to prevent hypothermia
- exposure-rewarming cycles for sentry duty
- fluid replacement schedule

B. pattern detection:

- sources of potential cold weather injuries in current scenario(s)

C. links to:

- cold stress physiology, medicine, and operational on-line references
- multimedia cold injury case presentations

<u>9.3 High altitude:</u>

A. optimum values:

- ascent profile
- oxygen utilization
- acetazolamide schedule

B. pattern detection:

- sources of potential altitude related syndromes in current scenario(s)

C. links to:

- altitude physiology, medicine, and operational on-line references

- multimedia altitude illness case studies

9.4 Injuries:

A. optimum values:

- training marches - distance and number per month
- load carriage configuration
- boot and sock combination

B. pattern detection:

- scenarios conducive to excess risk of musculo-skeletal injuries

C. links to:

- biomechanics, injury prevention, and sports medicine references
- multimedia injury prevention and treatment case studies

9.5 Nutrition:

A. optimum values:

- caloric intake
- nutrient and food group balance
- salt intake

B. pattern detection:

- scenarios conducive to weight loss, salt depletion

C. links to:

- references on nutrition, nutritional content of food items
- multimedia nutrition and electrolyte case studies

9.6 Logistics:

A. optimum values:

- potable water requirements
- rations - type, number, weight
- IV fluids
- other medical supplies
- evacuation resources

B. pattern detection:

- scenarios that will require greater than expected medical support

C. links to:

- medical logistics references

10.0 Data filter: this module allows the user to select what data are to be displayed, retrieved, or saved. The user selects the type of data that are of particular relevance to the situation. This allows the user to focus on those elements that are important and exclude output which may, for the particular application, be considered clutter. This improves the quality of the output.

11.0 Display mode: this module allows the user to select how the desired information is displayed. Frequently utilized data input-output systems include: keyboards and video terminals, printers, and digital storage (such as magnetic or optical disks). The user may choose to view or output data as graphs, tables, text, or data listings (in lengthy or summary formats).

12.0 Display and output data parameter adjustment: this functional module allows adjustment of the output to suit the situation and interests of the user.

This concludes the description of the components of the governing top-level design flowchart.

DESIGN AND IMPLEMENTATION ISSUES

The proposed software design is broad in scope. It is innovative with regard to integrating multiple but related environmental medicine and physiology knowledge bases. It will have practical utility for a wide variety of operational and training environments. However, implementation, in its entirety, will entail an extensive effort requiring considerable resources and time.

An important resource that will facilitate the development of the proposed product is a comprehensive database of the results of research studies conducted at USARIEM designated the "USARIEM Soldier Performance Database" (GEO-Centers, 1992). This will allow for expansion and further validation of the predictive physiologic response modules for heat, cold, and altitude stress.

A state of the art software product today, mandates consideration of multimedia techniques. Use of multimedia will require special provisions for video and photographic production and editing. This is discussed below.

PROTOTYPING AND PROOF OF CONCEPT

Prototyping can prove the technical feasibility of the project. It serves as the engineering mock-up for demonstration, testing and validation. It can assist in choosing between design options, and allows for realistic appraisal for trade-off analysis and decision making. Additionally it provides a means to identify interface human factor issues, alternative solutions, and serves as a vehicle for potential users to suggest changes and modifications.

For a software project such as this, the prototype facilitates development of input and output interfaces, obtaining feedback from potential users, concept

demonstration, and feasibility analysis. The user interface modules can be isolated from the computational modules. Data structures and module interfaces with their argument lists are defined so that the separate modules can interact with each other. This then permits parallel development of the core computational modules and interface modules. On the other hand, some stages of the programming may be accomplished sequentially in a top-down approach, e.g., first, development of the interface to assist with resolving usability issues, second, development of the missing numerical and utility routines (or vise versa in a sequential bottom-up software development approach). If, in specific instances, numeric routines or algorithms do not exist, are in development and validation, or are not sufficiently inclusive, then dummy routines or simulated data files can be substituted. This permits demonstration capability, pending the availability of adequately validated numeric models. In other words a proof-of-concept prototype does not initially require completely validated algorithms. Naturally if validated computational modules exist, as it does for heat stress/strain, then so much the better.

HUMAN FACTORS

Aesthetics is an important factor affecting user acceptance and satisfaction with a software product. Commercial software has raised the quality of input and output interfaces to very high levels. The user typically desires software products that have professional quality interfaces, graphics, ease of use, rapid learning curve, and on-line assistance or help. This does not, however, supersede the necessity to place great emphasis in the design and implementation phases on developing a robust technical core. Without this, the product will not be operationally useful.

STRUCTURE

The product must reflect a design structure that allows for a coherent development and upgrade schedule (Booch, 1991). Without an underlying well defined structure a software project will tend to develop extemporaneously without clearly defined and integrated end points. Implementation is not likely to be as efficient. A documented structure imposes direction, guidance, and constraints for the implementation and serves as historical record of the evolution of the product. If a project team is utilized, it permits team members to integrate their activities and understand how their efforts and responsibilities tie into the development of the final product.

MODULARITY

The intermediate and detail level designs should exploit the advantages of modularity (Fairley, 1985),i.e., isolation of separate functional components into distinct software modules. This prevents entangling multiple functions into long multipurpose software routines that are difficult to interpret, test, debug, or upgrade. This is a generic technique that applies to standard as well as object-oriented implementations.

Figure 5 below illustrates a modular design scheme for the proposed product. Each rectangular element represents a functional module which in some cases could be decomposed into submodules. At the core are the numeric modules primarily concerned with generating the time-dependent physiologic responses. A separate set of modules handle the interface. Other modules retrieve data from storage media and sensors. An external module (a separate but supporting utility program) adjusts model parameters adaptively from data in the USARIEM Soldier

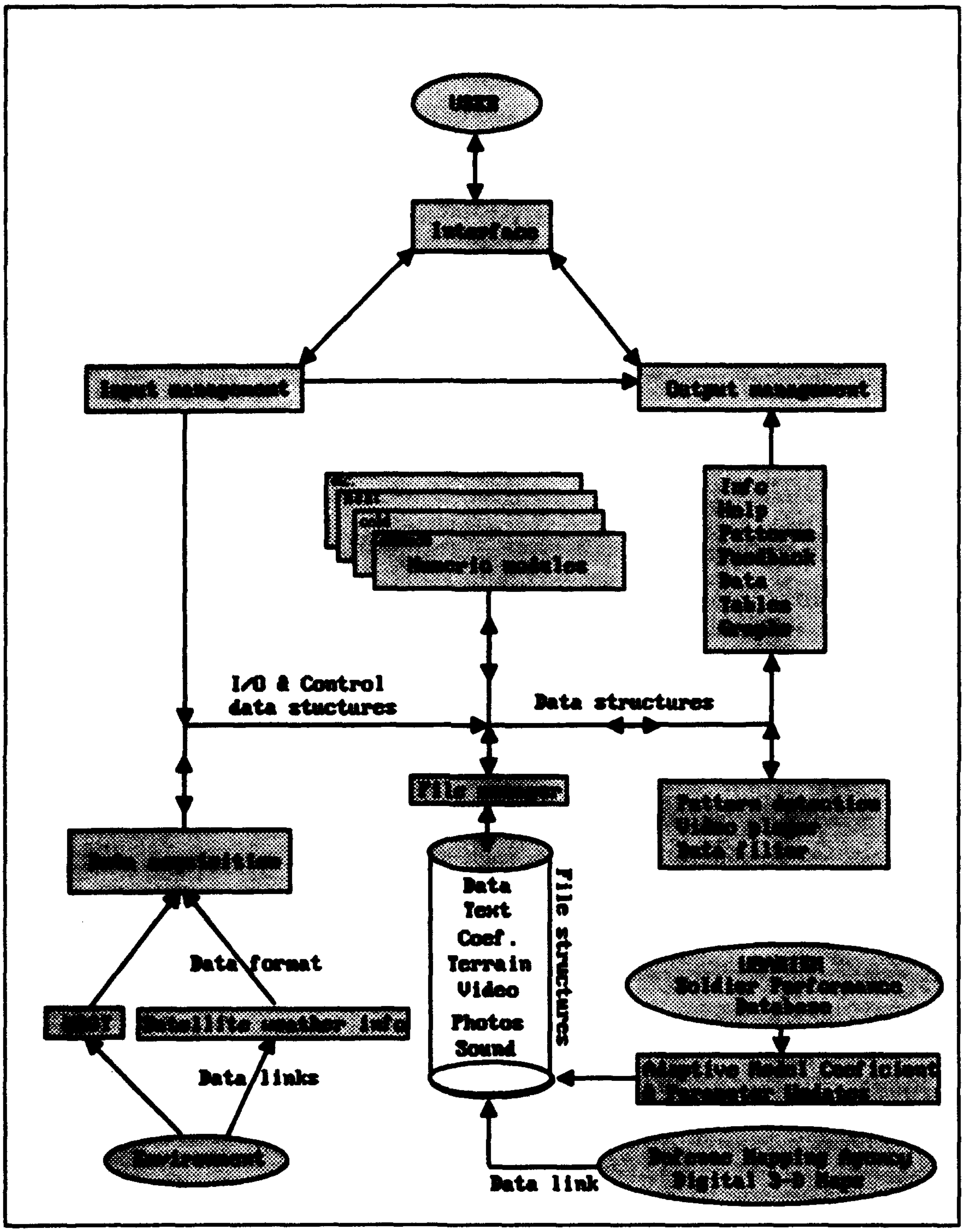

Figure 5. Modular elements

Performance Database and makes them available to the environmental workstation in the form of a data file.

A modular approach allows the product to be viewed as a system with loosely coupled or functionally independent units. This facilitates upgrading or testing specific components of the product. It also allows the product to be tailored or scaled for a particular type of user or requirement. That is, it facilitates constrained customization. Some modules, for example, may be included for a version of the product utilized for classroom based training, but deleted for an operational field version.

The manner in which functions, processes, or interfaces are implemented should be transparent not only to the user, but also to higher level program structures. That is, once the individual modules satisfy testing and performance requirements they can be collated in a compiled library of project functions that are then accessed by their interfaces. This requires only knowledge of the function, procedure, or module name; the encapsulated functionality, and a detailed understanding of the input-output argument list.

MULTIMEDIA

The incorporation of multimedia in the product can expand the scope and potential usefulness. It certainly may improve initial user acceptance and interest. In some cases it may also improve learning retention and impact positively on usability. On the other hand, ad hoc multimedia additions that are not tightly integrated and supportive of the main objectives of the workstation may add glitz but little or no additional substance. Adding video, sound, or other multimedia components to the proposed application may impose considerable additional design and implementation costs.

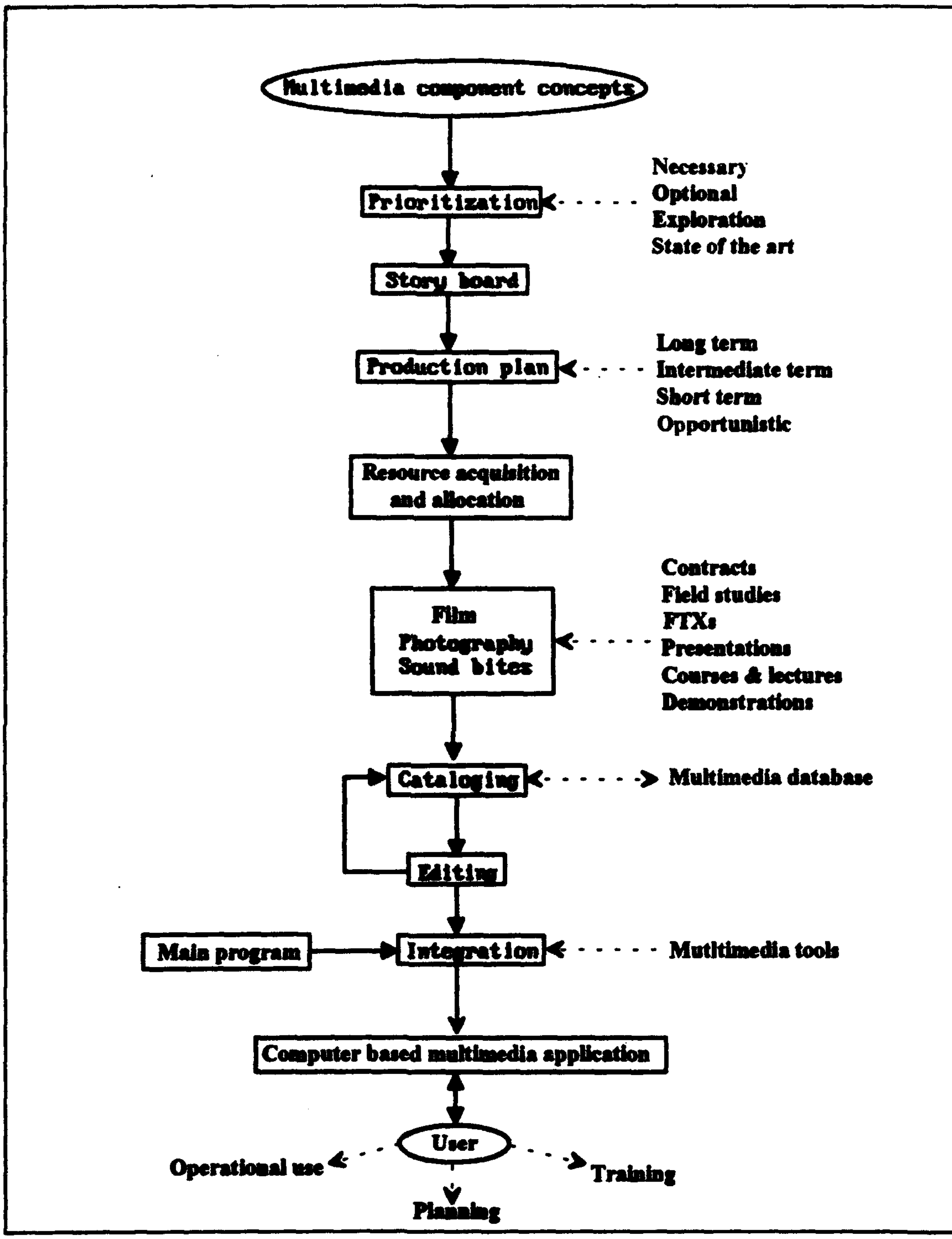

Figure 6. Multimedia development process.

Figure 6 illustrates a suggested sequence of steps for planning, implementing, and incorporating multimedia into a software product. The design effort progresses from concept formulation to planning, resource management, obtaining the media, editing, and seamless integration with the application.

OBJECT AND EVENT ORIENTED PROGRAMMING

Object oriented design and programming is currently touted as the preferred programming paradigm (Booch, 1991). In the future, it may be superseded by other programming techniques. Nonetheless, it currently is advocated as the implementation method of choice. Object oriented software facilitates dynamic generation of various objects, whether they be interface objects such as input-output windows, metaphors of real objects such as icons representing soldiers or units (collections of soldier and equipment objects), or functional objects that represent processes, states, or conditions.

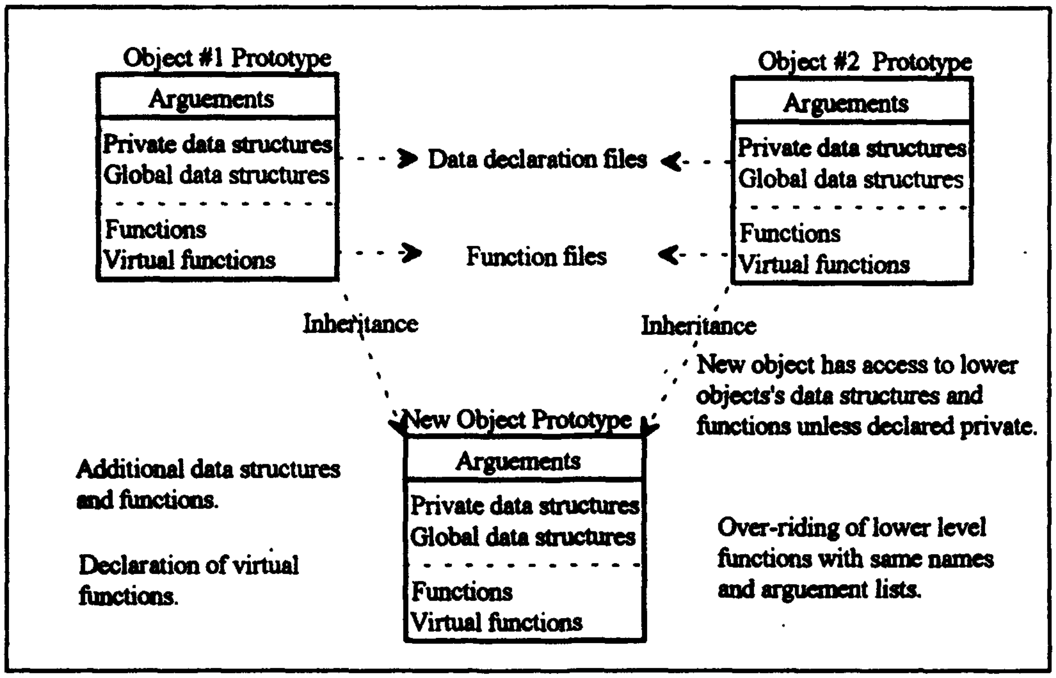

Figure 7. Object type structures and inheritance

Objects encapsulate data elements, structures, and the functions or procedures that modify their values or contents (see figure 7). The data are typically private by default, i.e., the data elements and structures are not directly *accessible to other objects. They can be accessed only by use of the owning* object's functions. Private data represent internal state variables not directly observable by users of the objects. By a user, one means another object or the main program (object) itself. Other data elements, however, may be made directly accessible by special declarations such as "public".

Object declarations often utilize inheritance to utilize the data structures and/or functionality of more simple object types. This can result in a hierarchy of objects as depicted in figure 8.

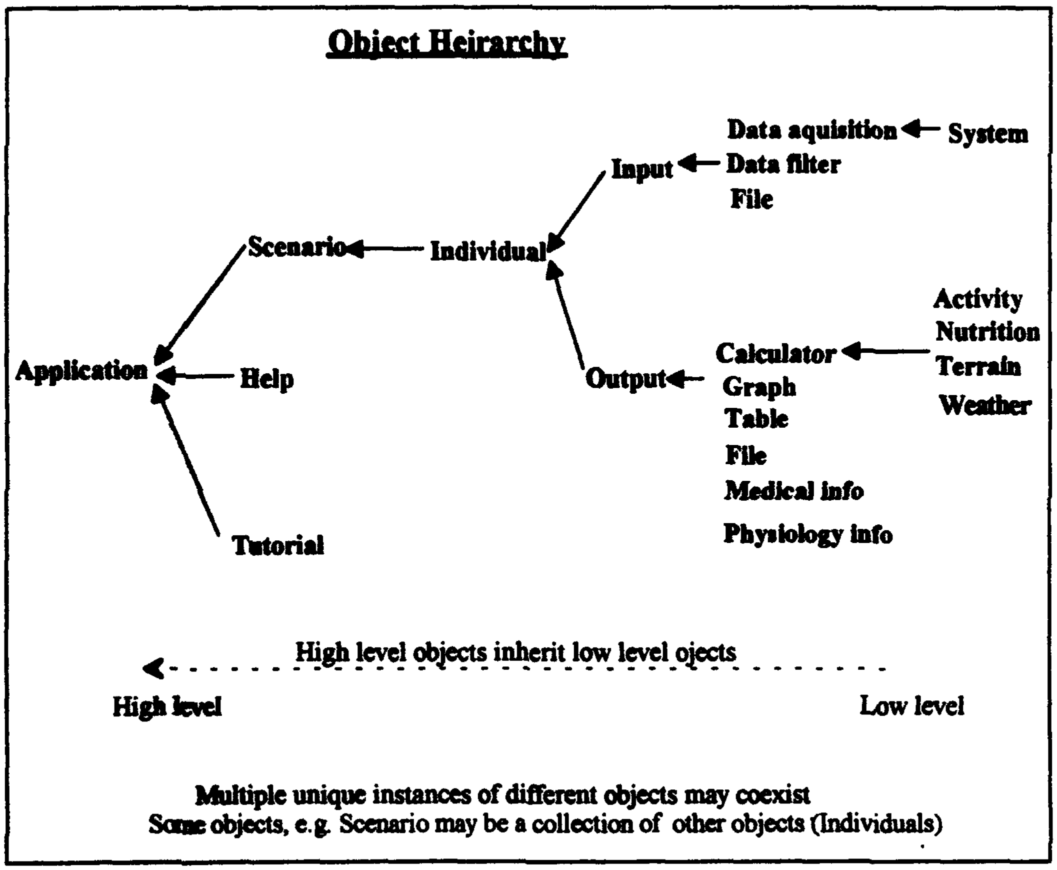

Figure 8. Object hierarchy.

Object-oriented programming is reputed to facilitate program maintenance and upgrading as compared to more conventional programming methods. Certainly it makes sense that programs written for use with object-oriented operating systems will likely be more efficient in utilizing system level resources (such as windows) if they themselves followed the object-oriented paradigm. Overriding the issue of object-oriented programming, however, are issues such as those discussed above: i.e., comprehensive project management and organization, a design scheme with flow charts, use of generic good programming techniques such as modularity, a thorough understanding of the scope of the project, availability of sufficiently flexible and powerful programming tools and aids, and a good programming, editing, and testing environment.

Event-oriented programming is a different concept. However, object and event directed methods can, and often should, coexist. Event-oriented programming can greatly facilitate software development. The software developer is not required to implement routines that monitor, capture, and direct responses to user, hardware, or software generated events or interrupts. An example of a user-generated event is a click of a mouse button. Hardware events can derive from an attached timer for sampling a WBGT meter output. The software module itself can trigger an event by designating, via a change in variable status, that a predesignated type of event has occurred.

Use of object and event-oriented programming techniques are options that have recently become widespread and recommended. They, however, are not mandatory. It is part of the wide scope of implementation issues that involve a host of trade-off decisions.

PROGRAMMING LANGUAGE

There is often considerable debate when contemplating a software project as to which programming language is best. One must weigh contractual and institutional requirements and guidelines, the experience and training of the programmers at hand, availability of software tools and quality of the program development environment, technology trends with estimates of the longevity and evolutionary direction of the language, transportability across different operating systems, as well as other considerations for each of the candidate languages.

Currently, regardless of the software language, a large program is very difficult to understand by perusing only its code. Well organized code is necessary, but it must also be accompanied by documentation that clearly and concisely describes what the program does and how it does it. This is accomplished by use of both graphical and narrative means. Considerable documentation of the governing concept, high level design scheme, preliminary detailed design, and data structures should be accomplished prior to implementing any code at all. A hierarchy of flow charts for the project and its components are typically developed during the exploratory and design phases of the project. These are the blueprints that describe what the program will do and how the user and hardware devices will be able to interact with it. These design documents allow program maintenance and changes at later dates by personnel not necessarily involved in the initial development effort. This must be accompanied by configuration control and management; one major purpose of which is to prevent documentation from falling out of phase with the incessant changes that developers tend to make when refining or redefining their software modules.

Whether or not good documentation and programming techniques and configuration management are employed may be more important than the selection of a specific programming language.

TESTING

Testing is an integral part of, but not the first step, in the software quality control effort. Rational modern software design practices emphasizes quality control from project inception. This usually leads to minimization of testing requirements. Algorithms should be analytically evaluated prior to software development to detect possible problematic behavior. For example, one would want to identify inputs that lead to singularities or sign changes in various formulas. It may be far easier to characterize a difficulty during the analysis part of a project than during the coding, testing, and debugging cycles. Up front, quality design efforts will identify the conditions that merit error trapping routines, special logic, or parameter limits. It also identifies possible developmental difficulties and technical risks.

Software testing is usually best accomplished via a bottom-up modular approach. Each module is tested as it is developed. Particular attention is directed toward behavior at end points of parameter ranges. The outputs for numeric algorithms are graphed versus the permissible range of independent parameters and compared with the analytic results. Logical constructs need to be clear and kept as simple as possible. All possible branches within a module should be tested because testing all the branches of the integrated program structure may be practically impossible.

CONCLUSION

This technical report provides an innovative design concept for a military environmental medicine and physiology software-based workstation. The principal components of the structure were delineated and various design and implementation issues were discussed. This product will utilize and integrate previously developed USARIEM models for responses to environmental stressors. It will be modular in design, exploit multimedia, and be capable of being utilized in operational and training modes. Additionally, it will incorporate a considerable amount of the USARIEM technical knowledge base as on-line text and tutorial. In its full maturity, it will also have the ability to incorporate real-time data from WBGT meters, remote sensing weather satellites, and global position sensors.

Emphasis is placed on prototype development that facilitates the design and implementation process and provides a framework for modular upgrades. These include replacement of initial stub or nonvalidated components with operational validated ones. The prototype can be used to identify areas where further research is required as well as defining and refining the user interface.

Significant software development issues were discussed in this technical note. Of these, the most important include comprehensive design documentation, liberal use of flow charts, definition of data and object structures, as well as use of modularity during implementation and testing.

Preliminary efforts are underway to implement a workable prototype. The scope of this project is ambitious but not unrealistic. It provides a long term blueprint for integration of the modeling and simulation efforts at USARIEM, provides a structure that identifies requirements for further research, and expands utility by incorporating features for training.

The goal is to provide the military health care planner with a comprehensive operationally oriented environmental medicine and physiology software decision and planning aid that also has built-in training capabilities. It will contribute to tactical planning by alerting medical and nonmedical commanders and staffs of operational conditions that will impose excess environmental stress. The operational options can then be modified in the recommended manner to reduce the likelihood of environmental stress casualties. This will help ensure that the maximum number of soldiers are available to accomplish the tactical mission in as high a state of physiological readiness as possible.

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